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16. ABSTRACT

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THE OCCURRENCE OF ACID PRECIPITATION ON THE WEST COAST OF THE UNITED STATES

CHARLES F. POWERS

Corvallis Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 200 S.W. 35th Street, Corvallis, Oregon 97330, U.S.A.

and

DANNY L. RAMBO

Northrop Services, Incorporated, Environmental Sciences Group, 200 S.W. 35th Street, Corvallis, Oregon 97330, U.S.A.

Abstract. Compilation of published and unpublished data shows acid precipitation to be more widespread in the Pacific coastal states than is generally recognized. Although information is scattered and discontinuous, precipitation is definitely acidic in the Los Angeles Basin and north-central California, and in the Puget Sound region in Washington. Acid rain occurrences have been observed in western and eastern Oregon, but data are inadequate for regional generalization. New stations currently being established in Washington and Oregon, largely in resposnse to the recently renewed activity of Mount St. Helens, will greatly facilitate assessment of precipitation acidity in the Northwest.

1. Introduction

The developing problem of acid precipitation has lately received much attention in the eastern United States; it has been thoroughly documented that all states east of the Mississippi River routinely receive acid rain (pH < 5.6) (Likens *et al.*, 1979). Much less attention has been paid to the possibility of similar situations in the western states, with their generally smaller populations and fewer sources of acid precursors. Recurring reports of acid rain incidents in the Pacific coastal states (e.g. Larson *et al.*, 1975; Liljestrand and Morgan, 1978) prompted us to compile certain existing information on precipitation chemistry in Washington, Oregon, and California, to see whether a problem, real or potential, exists, and to determine the physical resources devoted to the study of precipitation chemistry in this region. A search of the literature, together with personal inquiries, revealed that acid precipitation does occur regularly on the West Coast. This phenomenon is receiving increasing study.

Collection stations designed to monitor precipitation at specific sites over extended periods have been limited in the coastal states, and most of the information reviewed in this paper covers a relatively short time period. The following active network-affiliated stations were identified:

- WMO/EPA/NOAA – Pendleton, Oregon; Bishop (Inyo County), California. (The entire WMO/EPA/NOAA network was transferred to the National Atmospheric Deposition Program (NADP) in April 1980. Their proper designation is now WMO/EPA/NOAA/NADP.)
- Environmental Measurements Laboratory, U.S. Department of Energy (DOE) – Seattle, Washington; Beaverton, Oregon; Riverside, California; Richmond, California.

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TABLE I

Precipitation acidity in California

Location	Date	pH		Selected ions, μeq l^{-1}				Sample type	Sampling frequency	Source
		Average	Range	SO_4	NO_3	NH_4	Ca			
North-Central California/San Francisco Bay Area:										
Berkeley	Dec 74–Apr 75	5.0	4.5–5.7	60.1	3.6	<10	25.5	Bulk	Event	McColl and Bush (1978)
Berkeley	Dec 77–Apr 78	4.8	—	—	—	—	—	Wet	Event	Bush (1979)
Berkeley	Nov 78–May 79	4.66	—	10.2	13.7	8.0	6.0	Wet	Event	McColl (1980)
San Jose	Nov 78–May 79	4.42	—	10.0	16.4	19.1	12.6	Wet	Event	McColl (1980)
Napa	Nov 78–May 79	4.84	—	11.7	16.4	12.1	4.6	Wet	Event	McColl (1980)
Hopland	Nov 78–May 79	5.10	—	6.2	11.1	9.7	3.3	Wet	Event	McColl (1980)
Hopland (NADP)	Oct 79–Apr 80	5.68	4.96–6.93	19.0	8.0	4.0	4.0	Wet	(21) Weekly	National Atmospheric Deposition Program (1979, 1980)
Challenge	Nov 78–May 79	4.88	—	8.6	19.9	11.9	10.9	Wet	Event	McColl (1980)
Tahoe City	Nov 78–May 79	5.17	—	13.3	6.7	4.1	4.3	Wet	Event	McColl (1980)
Kearney (Parlier)	Nov 78–May 79	4.96	—	13.8	43.4	40.0	8.0	Wet	Event	McColl (1980)
Davis	Nov 78–May 79	5.20	—	19.0	22.6	35.5	5.6	Wet	Event	McColl (1980)
Davis (NADP)	Dec 78–Apr 80	5.86	3.91–7.03	47	31	43	12	Wet	Weekly	National Atmospheric Deposition Program (1979, 1980)
Livermore[a] (U.S. Dept. Energy)	May 77–Apr 79	5.2	4.8–5.5	48.4	51.3	48.3	22.1	Wet	(12) Monthly	Toonkel (1980)
Richmond[a] (U.S. Dept. Energy)	Nov 76–Mar 77	5.0	4.2–5.6	87.7	47.0	72.5	21.6	Wet	(5) Monthly	Toonkel (1980)
Petrolia	Nov 71–Jan 72	5.15	4.9–5.6	<4–102[b]	<1	2	2	Wet	Event	Kennedy *et al.* (1979)

[a] Dry deposition also reported but not included here.
[b] Most determinations reported as below analytical limit.

Table I *(continued)*

Location	Date	pH		Selected ions, μeq l^{-1}				Sample type	Sampling frequency	Source
		Average	Range	SO_4	NO_3	NH_4	Ca			
Honeydew	Nov 71–Jan 72	5.3	4.9–5.5	<4–94[b]	<1	—	3	Wet	Event	Kennedy *et al.* (1979)
Menlo Park	Nov 71–Dec 71	5.2	4.5–6.1	<2–100[b]	2	—	9	Wet	Event	Kennedy *et al.* (1979)
Menlo Park	Winter 57–58	5.95	5.4–8.5	37	2	—	38	Bulk	Irregular	Whitehead and Feth (1964)
Menlo Park	Winter 58–59	5.6	4.9–6.8	29	3	—	40	Bulk	Irregular	Whitehead and Feth (1964)
Boonville	'rainy seasons' 77–79	—	3.6 (lowest value)	—	—	—	—	Wet	Event	R. Reynolds, cited by McColl (1980)
Sacramento	'rainy seasons' 77–79	—	3.5 (lowest value)	—	—	—	—	Wet	Event	R. Reynolds, cited by McColl (1980)
Clear Lake sites:										
Central-Upper Lake	May 77–Apr 78	5.4	4.9–6.0	—	—	—	—	Bulk	Weekly	D. Weber, USEPA (personal communication)
Middleton	May 77–Apr 78	5.2	4.8–5.9	—	—	—	—	Bulk	Weekly	D. Weber, USEPA (personal communication)
Sawmill	May 77–Apr 78	5.6	5.0–6.6	—	—	—	—	Bulk	Weekly	D. Weber, USEPA (personal communication)
Los Angeles Basin:										
Azusa	Nov 78–Mar 79	4.66	3.56–5.86	37.7	43.9	36.2	15.3	Wet	Event	Morgan and Liljestrand (1980)
Los Angeles	Nov 78–Mar 79	4.49	3.92–5.43	55.5	34.0	35.9	14.6	Wet	Event	Morgan and Liljestrand (1980)
Long Beach	Feb 79–Mar 79	4.54	3.96–5.29	50.9	19.2	14.3	8.8	Wet	Event	Morgan and Liljestrand (1980)

[b] Most determinations reported as below analytical limit.

Table I *(continued)*

Location	Date	pH		Selected ions, μeq l^{-1}				Sample type	Sampling frequency	Source
		Average	Range	SO_4	NO_3	NH_4	Ca			
Mt. Wilson	Oct 78–Mar 79	4.99	3.86–7.00	39.7	23.2	35.5	9.3	Wet	Event	Morgan and Liljestrand (1980)
Riverside	Nov 78–Mar 79	4.97	4.25–6.44	33.4	32.6	33.7	17.2	Wet	Event	Morgan and Liljestrand (1980)
Westwood	Sep 78–Mar 79	4.53	3.91–5.77	42.4	27.0	20.8	10.2	Wet	Event	Morgan and Liljestrand (1980)
Wrightwood (90% snow)	Dec 78–Mar 79	4.90	4.54–5.41	7.2	10.6	0.9	3.9	Wet	Event	Morgan and Liljestrand (1980)
Big Bear Lake (snow)	Jan 79–Mar 79	5.42	4.51–6.45	6.5	17.0	7.5	9.3	Wet	Event	Morgan and Liljestrand (1980)
Pasadena	Sep 78–Mar 79	4.41	2.89–6.24	38.5	31.4	21.1	6.7	Wet	Event	Morgan and Liljestrand (1980)
Pasadena	Feb 76–Sep 77	4.06	—	60	75	9	33	Wet	Event	Liljestrand and Morgan (1978)
Bishop[a] (WMO)	1972	—	6.2–7.2	23	29	11	130	Wet	(5) Monthly	Environmental Data Service (1975)
Bishop (WMO)	1973	—	5.8–7.5	144	1	44	30	Wet	(5) Monthly	Environmental Data Service (1975)
Bishop (WMO)	1974	—	6.2–7.0	52	29	17	106	Wet	(6) Monthly	Environmental Data Service (1976)
Bishop (WMO)	1975	—	6.4–8.3	—	4	225	101	Wet	(5) Monthly	Environmental Data Service (1977)
Bishop (WMO)	1976	—	6.0–6.8	7	5	64	19	Wet	(3) Monthly	Environmental Data Service (1978)
Bishop (WMO)	1977	—	5.5–6.9	34	7	100	24	Wet	(5) Monthly	Environmental Data Service (1980)
Sierra Nevada Mountains (51 sites including 15 in Nevada)	Winters, 57–60	5.8 (median)	4.2–8.3	19	—	—	19	Snow	Once	Feth *et al.* (1964)
Sierra Nevada Mountains (26 sites including 6 in Nevada)	Jan 75–Apr 75	5.6	5.3–5.9	4.0	<1	—	2	Snow	Monthly	Brown and Skau (1975)

[a] Because of the long period of record and the separate literature references, the Bishop (WMO) station is reported here on an annual basis.

TABLE II

Precipitation acidity in Washington

Location	Date	pH		Selected ions, μeq l^{-1}				Sample type	Sampling frequency	Source
		Average	Range	SO_4	NO_3	NH_4	Ca			
Tacoma-Seattle Area (43 sites)	Nov 77 (single storm)	—	3.7–5.6	25	10	6	21	Wet	Event	Larson *et al.* (1975)
Bellevue-Seattle (3 sites)	Mar 79–Aug 80	—	3.8–4.9	—	—	—	—	Bulk and Composite	Event	J. Ebbert, U.S. Geological Survey (personal communication)
Seattle	Apr 72–May 72	4.9	4.1–6.6	—	—	—	—	Wet	Event	Riley (1972)
Seattle[a] (U.S. Dept. Energy)	Jul 76–Jun 79	4.3	4.0–4.5	85.8	26.4	12.7	26.1	Wet	(29) Monthly	Toonkel (1980)
North Cascade Mountains	1974–75	4.85	4.0–5.15	22	—	—	4	Wet	Event	Dethier (1979; personal communication)
Findley Lake (80% snow, Cascade Mountains)	Jun 79–Jun 80	—	4.5–6.0	—	—	—	—	Bulk	Monthly	C. Grier, University of Washington (personal communication)
Thompson Research Site	Feb 73–Feb 74	4.9	3.9–6.5	20	—	—	—	Bulk	Monthly	Johnson *et al.* (1979)
Hoh River watershed	1975–76	5.62	—	5	<1	<2	10	Bulk	2-weeks	Larson (1979)
Hoh River watershed	1976–77	5.83	—	5	<1	<2	16	Bulk	2-weeks	Larson (1979)
Stampede Pass (Cascade Mountains)	May 78–Nov 78	4.66	—	37.0	7.8	9.1	15.1	Bulk	Biweekly	Logan (1980)
Entiat Experimental Forest (central Washington)	1971–75	5.5	4.7–6.4	—	<1	2	21	Bulk	Event	Tiedemann *et al.* (1978)

[a] Dry deposition also reported but not included here.

TABLE III

Precipitation acidity in Oregon

Location	Date	pH		Selected ions, μeq l^{-1}				Sample type	Sampling frequency	Source
		Average	Range	SO_4	NO_3	NH_4	Ca			
Waldo Lake (Cascade Mountains)	Feb 69	4.9	—	—	<1	1	—	Snow	Once	Malueg *et al.* (1972)
Waldo Lake	Feb 70	5.4	—	—	<1	<1	—	Snow	Once	Malueg *et al.* (1972)
Cascade Head	Jun 63–May 64	6.1	5.7–6.3	—	<1	—	0	Bulk	Monthly	Tarrant *et al.* (1968)
Beaverton[a] (U.S. Dept. Energy)	May 77–May 79	5.4	4.6–7.6	22.3	10.0	7.4	12.3	Wet	Monthly	Toonkel (1980)
Pendleton[b] (WMO)	1972	5.8	4.8–6.95	10	6	11	23	Wet	(10) Monthly	Environmental Data Service (1975)
Pendleton (WMO)	1973	6.3	5.6–7.5	190(?)	5	2	45	Wet	(10) Monthly	Environmental Data Service (1975)
Pendleton (WMO)	1974	6.3	5.1–7.6	61	16	8	45	Wet	(8) Monthly	Environmental Data Service (1976)
Pendleton (WMO)	1975	5.6	5.0–6.2	16	4	5	45	Wet	(8) Monthly	Environmental Data Service (1977)
Pendleton (WMO)	1976	5.5	4.7–6.5	16	6	10	50	Wet	(9) Monthly	Environmental Data Service (1978)
Pendleton (WMO)	1977	5.4	4.6–6.6	18	5	12	24	Wet	(10) Monthly	Environmental Data Service (1980)
Corvallis	Jan 80–Feb 81	5.3	4.1–6.9	18	6	4	6	Wet	Weekly	National Atmospheric Deposition Program (1980), plus authors' unpublished data
Alsea	Jan 80–Feb 81	5.5	4.5–6.4	15	3	<1	5	Wet	Weekly	National Atmospheric Deposition Program (1980), plus authors' unpublished data
Andrews Forest	May 72–May 75	5.2	—	3	<1	—	7	Bulk	3-weeks	Sollins *et al.* (1980)
Bull Run watershed	Apr 1980	—	3.8–5.0	23	<1	—	—	Bulk	Irregular	Shulters and Clifton (1980a)
Bull Run watershed	May 80–Jun 80	—	4.0–5.6	15	2	—	—	Bulk	Irregular	Shulters and Clifton (1980b)
Bull Run watershed	June 1980	4.1–4.8[c]	4.0–5.0[c]	—	—	—	—	Wet	Event	T. Miller, U.S. Geological Survey (personal communication)

[a] Dry deposition also reported but not included here.

[b] Because of the long period of record and the separate literature references, the Pendleton (WMO) station is reported here on an annual basis.

[c] 7 samplers averaged pH 4.8 June 3–4, 4.2 June 10, 4.1 June 13. Range is extremes over those dates.

– National Atmospheric Deposition Program – Alsea, Oregon; Corvallis, Oregon; Davis, California; Hopland, California. Several additional NADP stations, for which data are not yet published, have been established very recently (see Table IV).

Data for the Pendleton and Bishop WMO sites extend back to 1972. None of the DOE or NADP stations existed prior to 1976. All of the network stations will, however, presumably be in operation for extended periods of time, and will provide continuous records in the future.

2. Precipitation Chemistry in the Coastal States

Data on precipitation pH for California, Washington, and Oregon are summarized in Tables I, II, and III. Average concentrations of sulfate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+), and calcium (Ca^{2+}) are also given, where available. Sulfate and nitrate are direct indicators of potential acidity and along with ammonium may represent anthropogenic contributions to the atmosphere. Calcium and ammonium can act to increase the pH of precipitation in samples where sulfate and nitrate concentrations suggest greater-than-observed acidity. Knowledge of these major ions, then, contributes to a more thorough interpretation and understanding of measured pH values, particularly in asssessing differences between geographic locations.

The tabulated data are from many sources and are not necessarily consistent with respect to such considerations as sampling and analytical methodology, sampling frequency, and sample type. The data presented here, therefore, should be used only in a general way; original works should be consulted for detail and precise information. We have presented pH values as averages and ranges over specified periods of time, and the four ions as averages only (ranges were frequently not given in the original source material). When necessary, we recomputed concentrations to the nearest *whole* $\mu eq\ l^{-1}$; more precise data in the tables are taken directly from the source.

The reader should be aware that precipitation in all three of these States is normally quite seasonal, with little rain occurring during the summer months. This is reflected in the dates of the studies contained in Tables I–III, most of which occurred between late fall and early spring. Annual averages from the long-term monitoring stations may represent samples taken during only six months of the year or less. Numbers in parentheses in the 'Sampling Frequency' column indicate the actual number of samples taken at the site during that year.

2.1. California

More information was found for California than for the other two states; records are concentrated in the north-central and Los Angeles Basin areas (Figure 1). Precipitation in those regions is definitely acidic; most of the recent pH values shown in Table I are less than 5.0. The low values of 3.6 and 3.5 at Boonville and Sacramento are particularly striking. Data from the DOE monitoring stations at Livermore and Richmond in the Bay

Fig. 1. Precipitation chemistry sampling locations.

area show somewhat higher pH values than reported by McColl (1980) for that same general area. Lake Tahoe and Big Bear Lake represent relatively remote mountainous areas. Precipitation at Big Bear Lake, the most easterly of Morgan and Liljestrand's (1980) Los Angeles Basin sites, showed a pH of 5.42, near that of 'normal' precipitation; at Tahoe City in the Sierras (McColl, 1980) average pH was somewhat lower at 5.17. Both of these mountain sites were less acidic than any of the other sites sampled by McColl, or Morgan and Liljestrand (the most recent California data) except for Davis, where pH averaged 5.2.

Although no individual sampling site in any of the three states has existed long enough to detect temporal trends, increasing acidity in the San Francisco Bay area can be inferred from the data of several observers, as pointed out by McColl and Bush (1978). Collections by Whitehead and Feth (1964) at two sites in Menlo Park in the winters of 1957–58 and 1958–59 showed average pH values of 5.95 and 5.6, respectively. Data for the same area by Kennedy *et al.* (1979) taken in November–December 1971 showed a lowering of the average pH to 5.2, an implied 3–4 fold increase in hydrogen ion activity. Their later comparison (Kennedy *et al.*, 1979) of these Menlo Park collections with collections made in January 1972 near the rural community of Petrolia revealed pH values of the same order, 5.1–5.2. McColl and Bush (1978) found somewhat lower pH levels, ranging from 4.5 to 5.7 (average, 5.0), at Berkeley in the winters of 1974–75, and, most recently, the Berkeley average (McColl, 1980) was 4.66, less than any previously reported. An approximate 12-fold increase in hydrogen ion activity (pH decrease from 5.6–5.95 to 4.66) in about two decades is suggested. Inferences such as this need to be treated cautiously, however, in view of the lack of continuity of the data and differences in site location, sample type, sampling frequency, equipment, and methodology. For example, pH data from the DOE Livermore and Richmond sites (Toonkel, 1980) do not appear to confirm the downward trend.

2.2. WASHINGTON

Data for Washington and Oregon are more sparse than for California. Information found for Washington (Table II) indicates a general prevalence of acid rain from the Seattle-Tacoma lowland metropolitan complex into the Cascade Mountains. Observations at Stampede Pass (Logan, 1980) provide evidence of acid conditions to at least the crest line. Larson's (1979) data from the Hoh River on the Olympic Peninsula are probably a good representation of baseline conditions before contamination by anthropogenic sources.

Feller (1977) reported precipitation pH averaging about 4.5, from August 1972 through July 1973, in a forest ecosystem 60 km east of Vancouver, British Columbia. These nearby observations provide additional evidence of acid precipitation in the Puget Sound region.

2.3. OREGON

Except for the most recent data, values of pH > 5.0 have typified the limited number of observations found for precipitation in Oregon (Table III). However, it must be

considered questionable as to whether such high values are typical of the state as a whole. It was noted earlier that observations relative to the Seattle-Tacoma area have shown the regular occurrence of acid precipitation in both the Puget Sound lowlands and adjacent Cascade Mountains. A potentially similar condition exists in Oregon with respect to the relatively densely populated Willamette Valley, just west and upwind of the Cascade Range. An increased number of sample sites in the valley and on the west slope of the Cascades, particularly downwind of the Portland metropolitan area, might reveal conditions similar to those demonstrated for the Puget Sound area. The need for greater sampling density is definitely indicated.

Weekly observations during June by the Environmental Protection Agency (EPA) at the Alsea and Corvallis NADP stations, and by the U.S. Geological Survey in the Bull Run Reservoir watershed (in the Cascade Mountains approximately 40 km east of Portland) have recorded the highest precipitation acidity in Oregon. There is indication of a relationship to the second major eruption of the Mount St. Helens volcano on June 12. Rain began the night of the eruption and continued during the following day. Rain collected at the EPA Corvallis NADP site at 7:00 a.m. on June 13 had a pH of 4.3; values later that morning rose to 5.1. The pH of the integrated NADP sample for the week of June 10–17 was 4.1; the corresponding weekly sample from the Alsea site was 4.5. Traces of volcanic ash were present in both collectors. The previous low at both stations was 4.9 on January 15, 1980, following a strong southwest storm. Seven samplers situated in the Bull Run Reservoir watershed averaged pH 4.8 on June 3–4, 4.2 on June 10, and 4.1 on June 13, the day following the second eruption, (T. Miller, U.S. Geological Survey, Portland, Oregon, personal communication). However, the June 13 value was only slightly lower than that for June 10, two days before the eruption. The relationship of the precipitation acidity to the volcano during that period is, therefore, not clear. Since the mountain is known to have been venting large quantities of SO_2 throughout this recent period of activity, it is possible that rain at Bull Run, which is much nearer the volcano than Corvallis or Alsea, has regularly been affected. Material from the second eruption, however, which was transported south and southwest by northerly winds, could have produced an acidifying effect on precipitation as far south as Corvallis and Alsea for the first time. North winds are rarely associated with precipitation in this region.

2.4. Future prospects

Increased interest by federal agencies in atmospheric deposition, and state and local concerns over air pollution generally, appear to be resulting in the establishment of critically needed additional sites for monitoring precipitation chemistry in the coastal states. At this writing, 18 new sampling stations are in some stage of development in Washington, Oregon, and California (Table IV; Figure 1).

A major impetus to this expanded coverage, at least in the Nothwest, has been the renewed activity of Mount St. Helens. Sulfur dioxide emissions from the volcano may be sufficient to significantly affect acid deposition rates in that region. The maximum estimated total daily anthropogenic emission of SO_2 for the state of Washington is about 280 T (H. Droege, Washington Department of Ecology, Olympia, personal communi-

TABLE IV

New precipitation sampling sites[a]

Location	Network	Operating agency
Washington		
Olympic National Park	NADP	U.S. Park Service
Mossy Rock	[c]	U.S. Geological Survey
Glenwood	[c]	U.S. Geological Survey
Kalama River mouth	[c]	U.S. Geological Survey
Vancouver	[c]	U.S. Geological Survey
Pasco	[c]	U.S. Geological Survey
Yakima	[c]	U.S. Geological Survey
Randle	[c]	U.S. Geological Survey
Oregon		
H. J. Andrews Experimental Forest	NADP	U.S. Forest Service
Medford	NADP	Bureau of Land Management
Vale	NADP	Bureau of Land Management
Fossil	[c]	U.S. Geological Survey
Sisters	[c]	U.S. Geological Survey
Bull Run	[c]	U.S. Geological Survey
Eugene	[b]	U.S. Geological Survey
California		
Sequioa-Kings Canyon National Park	NADP	U.S. Park Service
Fresno	[b]	U.S. Geological Survey
Long Beach	[b]	U.S. Geological Survey

[a] At the time of writing, these sites were either under construction, undergoing initial testing and calibration, or had been operational less than one month.
[b] Urban Runoff Studies.
[c] St. Helens Studies.

cation). This has been sufficient to produce regularly-occurring acid precipitation events in the Puget Basin (cf. Table II). The background (non-eruptive) SO_2 emission rate of Mount St. Helens between June 6 and October 28, 1980 varied between 470 and 2000 T day^{-1}, with a rough baseline of approximately 900 T day^{-1} (D. Harris and T. Casedevall, U.S. Geological Survey, personal communication). During that same period, temporary sampling stations intended primarily for monitoring effects of Mount St. Helens emissions recorded acidic events. Precipitation pH values at Merwin Dam were 4.8 on June 24 and 4.4 on August 30; Castle Rock recorded pH 4.1 on September 13, and Kennewick 5.1 on October 12 (J. Cline, U.S. Geological Survey, personal communication). Castle Rock, Merwin Dam, and Kennewick are located west, south, and east, respectively, from St. Helens. Previous evidence of acidification of precipitation by anthropogenic sources in the Puget Basin (Table II), however, makes it difficult to attribute the Merwin Dam, Castle Rock, and Kennewick observations to volcanic effects alone. As of January 1981, background emissions had declined to 100–400 T day^{-1} since October (T. Casedevall, personal communication). Continued

very low emission rates might result in strictly localized surface water effects, such as acidification of a small lake on Mount Baker, Washington (Bortleson *et al.*, 1977). The future impacts of emissions from these active volcanoes on precipitation, surface water, and ground water chemistry are at this time impossible to assess.

Many western lakes, streams, and soils are potentially sensitive to acidification (Bradford *et al.*, 1968; Galloway and Cowling, 1978; Welch and Chamberlain, 1981). Although a trend toward increasing precipitation acidity is suggested for the San Francisco Bay area, observations of precipitation chemistry in the west to date are too scattered, both in space and time, to permit definite identification of trends. The increasing number of monitoring sites will greatly enhance the risk assessment of acid precipitation for this region.

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